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Assessing the link between coastal wetlands and white shrimp fishery production in the northern Gulf of Mexico

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Abstract

We developed a stage-based matrix population model for white shrimp *Litopenaeus setiferus* to examine the links between habitat, stage-specific vital rates, and population growth rate, lambda (λ). Based on the available demographic rates, the model indicates that λ is orders of magnitude more sensitive to variability in survival of early life stages than it is to changes in adult survival or fecundity. This implies that 1) processes during early life stages regulate population growth rate and decouple parent stock size from subsequent recruitment to the fishery and 2) understanding the factors that regulate variability in these early mortality rates is a high priority for fishery management and habitat conservation. Given the functional role of salt marshes in regulating juvenile shrimp growth and mortality, the combination of the matrix with existing habitat models highlights the significance of marshes in the white shrimp life-cycle and the support of shrimp stocks. Matrix models provide a powerful tool for identifying critical life-stages and prioritizing knowledge gaps in our understanding of the factors regulating populations.

Key Words: marsh loss, habitat-mediated mortality, population persistence, matrix models.

Introduction

Coastal marshes of the northern Gulf of Mexico have long been recognized as essential nursery habitats for a range of nekton including many species of fisheries significance such as penaeid shrimp (Anderson et al. 1949, Turner 1977, Minello et al. 2003). Comparisons of density estimates of organisms among particular habitats can provide a basic index of relative habitat quality (e.g. Rozas et al. 2007), and high densities of juvenile shrimp within vegetated marsh habitats suggests marshes may be particularly important in the support of shrimp fisheries (Minello et al. 2008). However, to gain a true understanding of the relative importance of various habitats to the persistence of populations it is essential to place the value of individual habitats in the context of the entire life cycle (Beck et al. 2001), and to examine the processes regulating habitat value and functioning (Sheaves et al. 2006). In this study we develop a stage-based matrix population model for white shrimp *Litopenaeus setiferus* to identify the life stages which have the greatest influence on population size.

Model development and sensitivity analysis

Stage-based matrix population models provide a tool to estimate the sensitivity of population growth rate, lambda (λ) to changes in the vital demographic rates (mortality, growth, fecundity) of specific life-stages (Caswell 2000). Matrix models are populated with parameters representing the probabilities of individuals surviving from one life stage to the next and with the fecundity of each life stage (Caswell 2000). We divided the white shrimp life cycle into 5 life stages; egg/larvae, early postlarvae (PL), marsh juvenile, bay subadult, and offshore adult. The egg and larval stages were combined because no data were available for vital rates of these stages for wild white shrimp and thus combined survivorship had to be estimated from the model (see below). We separated the PL stage (6-27 mm TL) from the marsh juvenile stage (28-70mm) because our data indicated that there were substantial differences in mortality between these stages. The subadult bay stage was defined as shrimp 71 to 100 mm migrating through bays from marshes to offshore habitats (Lindner & Anderson 1956), while adults were larger shrimp in offshore waters. Because the timing and size of individuals at migration is variable (Lindner & Anderson 1956), the boundaries of these life-stages, although useful as a means for modeling, should be considered approximate.

Survivorship within the matrix model is a function of growth and mortality rates and stage duration. To parameterize the model, we produced a life table (Table 1) primarily based on mortality, growth, and fecundity estimates from published literature (Lindner & Anderson 1956, Zein-Eldin & Griffith 1969, Klima 1974, Nichols 1984, Rothschild & Brunenmeister 1984, Pauly et al 1984). For PL and juvenile rates, we analyzed population data from the NOAA Fisheries Galveston Lab (Minello et al. 2008). Egg/larval survivorship was estimated in the baseline model using λ of 1.11 estimated from three time series of adult stock size (SEAMAP: Nichols 2004, TPWD: Martinez-Andrade et al 2005, NOAA stock assessments: Nance 2007) following the methods of Dennis et al (1991) and then solving the matrix for egg/larval survival as the only missing parameter (Levin & Stunz 2005).

Table 1: Summary of white shrimp, *Litopenaeus setiferus*, life stages and demographic rates.

stage	TL (mm)	duration (days)	growth rate (mm/d)	daily Z	stage Z	survivorship	fecundity
egg/larvae	<6	16	-	-0.3918	-6.2686	0.0019	0
PL	6-27	30	0.75	-0.1169	-3.5070	0.0300	0
marsh	28-70	52	0.82	-0.0366	-1.9032	0.1491	0
bay	71-100	33	0.91	-0.0275	-0.9075	0.4035	0
adult	>100	234*	1	-0.0384	-8.9856	0.0001	500000

*adult stage duration = remainder of 365 days

We performed sensitivity analysis on the resulting 'baseline' matrix (Table 2) to determine the relative influence of changes in life-stage vital rates on population growth rate (λ), following the methods of Morris & Doak (2002) as summarized by Levin and Stunz (2005). Briefly, the technique involves providing a biologically realistic range of values for each of the vital rates in the model (derived from range in estimates used to develop the life table), and independently measuring the effect on λ of 500 randomly selected values for each vital rate from within the range of realistic values. A regression was developed between these vital rates and λ, and the proportion of variance explained in the regression provided an estimate of the relative importance of vital rates on population growth (Morris & Doak 2002, Levin & Stunz 2005).

Table 2: 'Baseline' stage-based population matrix for white shrimp. λ = 1.1132

	egg/larvae	PL	marsh	bay	adult
egg/larvae	0	0	0	0	500000
PL	0.001895	0	0	0	0
marsh	0	0.029987	0	0	0
bay	0	0	0.149091	0	0
adult	0	0	0	0.403532	0.000125

Given the demographic rates used to parameterize the baseline model (Table 1), the amount of variation in λ explained by egg/larval, PL, and marsh juvenile survival is an order of magnitude greater than that explained by bay subadult survival or adult fecundity, and two orders of magnitude greater than adult survival (Fig. 1). These findings are as expected for a short-lived highly-fecund marine species. The results suggest that factors influencing mortality rates of early life stages play a significant role in regulating shrimp stocks, in agreement with the weak stock/recruitment relationship in the white shrimp fishery (Nance 2007).

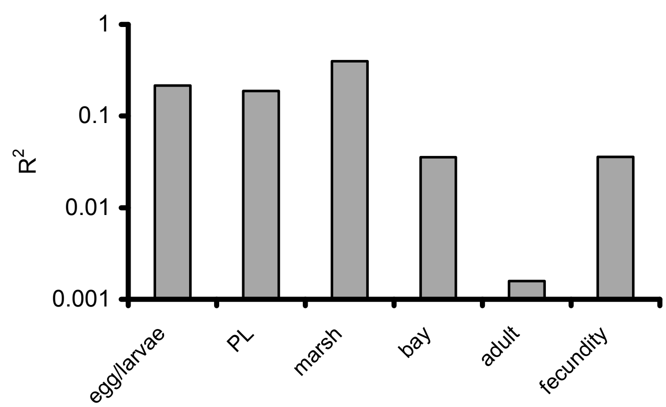

Figure 1: Relative influence of life stage vital rates on white shrimp population growth rate.

We utilized available shrimp distribution models and a GIS of Galveston Bay marshes (Minello et al. 2008) to explore the significance of changes in nursery habitats on shrimp stocks. The models indicate that even relatively small changes in access to vegetated marsh habitat can have larger impacts on shrimp stocks than adult fishing mortality. Although detailed quantitative interpretation of these preliminary models may not be appropriate, the findings help to clarify the relative importance of juvenile mortality rates and the functional role of marsh habitats in the white shrimp life-cycle, and the value of matrix models for identifying life-stages and habitats critical in the regulation of populations.

Conclusions

The data used to parameterize the model is somewhat limited (Table 1), and detailed interpretation of the model may not be appropriate. However, the life table data derived for white shrimp are in broad agreement with published values for other penaeids (Dall et al. 1990), and the conclusion that population growth rate is most sensitive to variations in early mortality rates seems robust. Given the functional role marsh habitats play in regulating juvenile shrimp growth and survival (Minello et al. 1989, Zimmerman et al. 2000), the model findings clarify the importance of marsh habitats in the context of the entire shrimp life-cycle. Although only a relatively small proportion of the juvenile white shrimp population may occupy vegetated habitats at any given time (Minello et al. 2008), models produced by combining shrimp distributions and a GIS of Galveston Bay with the matrix indicate that relatively small changes in access to vegetated marsh can have a profound influence on juvenile survival and population growth rate. The matrix also identifies the importance of egg/larval survival (Fig. 1). This value had to be estimated from the model due to a lack of data, thus highlighting the utility of matrix modeling for identifying important knowledge gaps in our understanding of life-cycles and the processes regulating populations. A clearer understanding of the processes that regulate variability in juvenile survival is high priority for the management of coastal habitats and shrimp stocks.

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References

Anderson WW, King JE, Lindner MJ (1949) Early stages in the life history of the common marine shrimp, *Penaeus setiferus* (Linnaeus). Biol Bull 96:168-172

Beck M, Heck K, Able K, Childers D, Eggleston D, Gillanders B, Halpern B, Hays C, Hoshino K, Minello T, Orth R, Sheridan P, Weinstein M (2001) The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. Bioscience 51:633-641

Caswell, H., 2000a. Matrix population models: construction, analysis, and interpretation. Sinauer Associates, Sunderland, MA.

Dall, W., B. J. Hill, P. C. Rothlisberg, and D. J. Staples. 1990. The biology of the Penaeidae. Academic Press, London

Dennis B, Munholland PL, Scott JM (1991) Estimation of growth and extinction parameters for endangered species. Ecological Monographs 61:115-144

Klima EF (1974) A white shrimp mark-recapture study. Trans Am Fish Soc 103:107-113

Levin P, Stunz G (2005) Habitat triage for exploited fishes: Can we identify essential ‘‘Essential Fish Habitat?’’ Estuar Coast Shelf Sci 64:70-78

Lindner MJ, Anderson WW (1956) Growth, migrations, spawning and size distribution of shrimp, *Penaeus setiferus*. Fish Bull 56:556-644

Martinez-Andrade F, Campbell P, Fuls B (2005) Trends in relative abundance and size of selected finfishes and shellfishes along the Texas coast: November 1975 – December 2003. Management Data Series 232. Texas Parks and Wildlife, Austin Texas

Minello TJ, Zimmerman RJ, Martinez EX (1989) Mortality of young brown shrimp *Penaeus aztecus* in estuarine nurseries. Trans Am Fish Soc 118:693–708

Minello TJ, Able KW, Weinstein MP, Hays C (2003) Salt marshes as nurseries for nekton: testing hypotheses on density, growth, and survival through meta-analysis. Mar Ecol Prog Ser 246:39–59

Minello TJ, Matthews GA, Caldwell PA, Rozas LP (2008) Population and production estimates for decapod crustaceans in wetlands of Galveston Bay, Texas. Trans Am Fish Soc 137:129-146

Morris WF, Doak DF (2002) Quantitative conservation biology. Sinauer Associates, Sunderland, MA.

Nance JM (2007) Stock Assessment Report 2006 Gulf of Mexico Shrimp Fishery. NOAA NMFS Galveston Texas

Nichols S (1984) Updated assessments of brown, white and pink shrimp in the U.S. Gulf of Mexico. Stock Assessment Workshop, Miami, May 1984

Nichols S (2004) Derivation of Red Snapper Time Series from SEAMAP and Groundfish Trawl Surveys. SEDAR-DW1.

Pauly D, Ingles J, Neal R (1984) Application to shrimp stocks of objective methods for the estimation of growth, mortality, and recruitment-related parameters from length-frequency data (ELEFAN I and II). *In:* Gulland & Rothschild (eds.) Penaeid shrimps: their biology and management. Fishing News Books, Farnham

Rothschild BJ, Brunenmeister SL (1984) The dynamics and management of shrimp in the northern Gulf of Mexico. *In:* Gulland & Rothschild (eds.) Penaeid shrimps: their biology and management. Fishing News Books, Farnham

Rozas LP, Minello TJ, Zimmerman RJ, Caldwell P (2007) Nekton populations, long-term wetland loss, and the effect of recent habitat restoration in Galveston Bay, Texas, USA. Mar Ecol Prog Ser 344:119-130

Sheaves M, Baker R, Johnston R (2006) Marine nurseries and effective juvenile habitats: an alternative view. Mar Ecol Prog Ser 318:303–306

Turner RE (1977) Intertidal vegetation and commercial yields of penaeid shrimp. Trans Am Fish Soc 106:411-416

Zein-Eldin ZP, Griffith GW (1969) An appraisal of the effects of salinity and temperature on growth and survival of postlarval penaeids. FAO Fishery Report 57

Zimmerman RJ, Minello TJ, Rozas LP (2000) Salt marsh linkages to productivity of penaeid shrimps and blue crabs in the northern Gulf of Mexico. *In*: Weinstein & Kreeger (eds) Concepts and controversies in tidal marsh ecology. Kluwer, Dordrecht, The Netherlands